1. A compact, energy-recycling homogenizer module for use in an illumination system

characterized by:

a) folded optical channel means having at least one entry position and an exit position,

b) entry port means at said folded optical channel entry;

c) a plurality of parallel, internally-reflective longitudinal surfaces in said folded optical channel;

d) a plurality of internally-reflective latitudinal surfaces in said folded optical channel, perpendicular to said longitudinal surfaces; and

e) exit port means at said folded optical channel exit position;

whereby such folded optical channel provides a complex multi-reflection uniformizing effect as most rays of a bundle of light rays in an entering beam travel with multiple complex internal reflections from entry means to exit means, and some light rays that are reflected back toward said entry port means are re-reflected in the forward direction and returned for recycling.

2. A compact, energy-recycling homogenizer module for use in an illumination system

characterized by:

a) folded optical channel means having a single entry position and a single exit position,

b) entry port means at said folded optical channel entry position;

c) a plurality of parallel, internally-reflective longitudinal surfaces in said folded optical channel;

d) a plurality of internally-reflective latitudinal surfaces in said folded optical channel, perpendicular to said longitudinal surfaces; and

e) exit port means at said folded optical channel exit;

whereby such folded optical channel provides a complex multi-reflection uniformizing effect as most rays of a bundle of light rays in an entering beam travel with multiple complex reflections from entry means to exit means, and some light rays that are reflected back toward said entry port means are re-reflected in the forward direction and returned for recycling.

3. A compact, energy-recycling homogenizer module for use in an illumination system for optical projection

characterized by:

a) a conjoined folded optical channel with at least two entry channel portions and a set of return channel portions culminating in a single shared exit channel portion;

b) a set of entry ports at entries to said folded optical channels;

c) a plurality of parallel, internally-reflective longitudinal surfaces in said folded optical channel;

d) a plurality or internally-reflective latitudinal surfaces in said folded optical channel, perpendicular to said longitudinal surfaces, and

e) exit means at said folded shared-exit optical channel.

whereby such folded conjoined optical channels from each entry port to said shared exit port provides a complex multi-reflection uniformizing effect as most rays of a bundle of light rays in each entering beam travel with multiple complex reflections from each entry port to shared exit means and some light rays that are reflected back toward an entry port are re-reflected in the forward direction and returned for recycling.

4. A compact, high-efficiency, energy-recycling illumination system characterized by:

a) a light source;

b) collection optics for collecting and shaping light from said light source; and

c) an energy-recycling homogenizer module appropriately juxtaposed to accept light from said collection optics, having a folded set of internally-reflective longitudinal directing surfaces and latitudinal returning surfaces for providing complex multi-reflection directing and returning intensity uniformization and energy-recycling .

5. A compact, high-efficiency, energy-recycling illumination system according to Claim 4,

further characterized in that:

said light source is a high-pressure arc lamp.

6. A compact, high-efficiency, energy-recycling illumination system according to Claim 4,

further characterized in that:

said light source provides a broad-spectrum white light emission.

7. A compact, high-efficiency, energy-recycling illumination system according to Claim 4,

further characterized in that:

said light source is an ultraviolet lamp.

8. A compact, high-efficiency, energy-recycling illumination system according to Claim 4,

further characterized in that:

said light source is a laser.

9. A compact, high-efficiency, energy-recycling illumination system according to Claim 8,

further characterized in that:

said laser is an ultraviolet laser.

10. A compact, high-efficiency, energy-recycling illumination system according to Claim 8,

further characterized in that:

said laser is an excimer laser.

11. A compact, high-efficiency, energy-recycling illumination system according to Claim 4,

further characterized by:

condenser optics for accepting the uniform output of said homogenizer and providing such light onto an object surface.

12. A compact, energy-recycling homogenizer module according to Claim 1,

further characterized in that:

said optical channels are hollow and said internally-reflecting surfaces are mirrored surfaces.

13. A compact, energy-recycling homogenizer module according to Claim 1,

further characterized in that:

said optical channels are solid, made of a bulk optical material, and internal reflections in such solid channels take place by the phenomenon of total internal reflection.

14. A compact, energy-recycling homogenizer module according to Claim 1,

further characterized in that:

said optical channels are solid, made of a bulk optical material with mirrored internally-reflecting surfaces causing such internal reflections.

15. A compact, high-efficiency, energy-recycling illumination system

characterized by:

a) a light source;

b) collection optics for collecting and shaping light from said light source and forwarding such collected and shaped light; and

c) an energy-recycling homogenizer module having a single entry port appropriately juxtaposed to accept light from said collection optics, having a folded set of internally-reflective longitudinal directing surfaces and latitudinal returning surfaces for a complex multi-reflection directing and returning intensity uniformization and energy-recycling.

16. A compact, high-efficiency, energy-recycling illumination system characterized by:

a) a light source;

b) collection optics for collecting and shaping light from said light source and forwarding such collected and shaped light in two beams; and

c) an energy-recycling homogenizer module having two entry ports appropriately juxtaposed to accept said two beams of light from said collection optics, each said entry port leading its beam to a respective folded set of internally-reflective longitudinal directing surfaces and latitudinal returning surfaces for a complex multi-reflection directing and returning intensity uniformization and energy-recycling; and

d) condenser optics for accepting the uniform output of said homogenizer and providing such light onto an object surface.

17. A compact, energy-recycling homogenizer module according to Claim 12,

further characterized in that:

said homogenizer is hollow, comprising:

a box enclosure set of two single-face mirror base members and two single-face mirror strips, each mirrored on one side only; forming an internally-mirrored box with open entry end and exit end;

a single-face mirror strip having an entrance aperture as entry port, closing the entry end of said box enclosure set, with entry port near a first corner;

a single-face mirror strip for use as a returning mirror opposite such entry port;

a set of two dual-face mirror strips, mirrored on both sides, that are shorter than said single-face mirror strips, mounted within said box enclosure set so as to define an internally-mirrored, folded channel having an optical axis with two returns, from said first corner to a diagonally-opposite third corner; and

transparent exit port means near said third corner.

18. A compact, energy-recycling homogenizer module according to Claim 17,

further characterized in that:

said dual-face mirror strips overlap in the placement parallel to said optical axis.

19. A compact, energy-recycling homogenizer module according to Claim 13,

further characterized in that:

said bulk optical material is configured into separate optical channels constructed by providing slots in said solid optical material such that resulting slot surfaces are substantially smooth to provide total internal reflection in the bulk channels.

20. A compact, high-efficiency, energy-recycling illumination system according to Claim 14,

further characterized in that:

said bulk optical material is configured into separate optical channels constructed by providing slots in said solid optical material such that resulting slot surfaces are substantially smooth and mirrorized to provide internal reflection in the bulk channels.

21. A compact, high-efficiency, energy-recycling illumination system according to Claim 4,

further characterized in that:

said collection optics focuses light from said light source into said entry port of said homogenizer, with a specified numerical aperture; and

the internally-reflecting surfaces of said homogenizer are so arranged that the numerical aperture of the light beam emerging from its exit port is equal to that of the beam entering its entry port.

22. A compact, energy-recycling homogenizer module according to Claim 13,

further characterized in that:

said exit port is coated with an anti-reflective coating to minimize reflections.

23. A compact, energy-recycling homogenizer module according to Claim 14,

further characterized in that:

said exit port is coated with a multilayer anti-reflective coating to minimize reflections.

24. A compact, energy-recycling homogenizer module according to Claim 2,

further characterized by:

a conical indentation in the region of the returning face of said homogenizer where central rays of the input beam are incident, so that such central rays are reflected at a specified angle from the optical axis.

25. A compact, energy-recycling homogenizer module according to Claim 3,

further characterized by:

a conical indentation in each of the regions of the returning face of said homogenizer where central rays of the input beams are incident, so that such central rays are reflected at a specified angle from the optical axis.

26. A compact homogenizer module for use in an illumination system according to Claim 1

further characterized in that:

the cross-sectional shape of each of said optical channels is a square.

27. A compact homogenizer module for use in an illumination system according to Claim 1

further characterized in that:

the cross-sectional shape of each of said optical channels is a rectangle.

28. A compact homogenizer module for use in an illumination system according to Claim 1

further characterized in that:

the cross-sectional shape of each of said optical channels is a hexagon.

29. A compact homogenizer module for use in an illumination system according to Claim 1

further characterized in that:

the cross-sectional shape of each of said optical channels is a circle.

30. A compact homogenizer module for use in an illumination system according to Claim 1

further characterized in that:

the cross-sectional shape of each of said optical channels is a triangle.

31. A compact homogenizer module for use in an illumination system according to Claim 1

further characterized in that:

the cross-sectional shape of at least one of said optical channels is different from the cross-sectional shape of another channel.

32. A compact homogenizer module for use in an illumination system according to Claim 1

further characterized in that:

the cross-sectional shape of the first one of said optical channels is circular and the cross-sectional shape of the last channel is rectangular.

33. A compact homogenizer module for use in an illumination system according to Claim 1

further characterized in that:

the cross-sectional shape of the first one of said optical channels is circular and the cross-sectional shape of the last channel is hexagonal.

34. A compact homogenizer module for use in an illumination system according to Claim 1

further characterized in that:

the cross-sectional shape of the first one of said optical channels is rectangular and the cross-sectional shape of the last channel is hexagonal.

35. A compact homogenizer module for use in an illumination system according to Claim 3

further characterized in that:

the composite cross-sectional shape of said homogenizer multiple optical channels is of the plus sign.

36. A compact homogenizer module for use in an illumination system according to Claim 35,

further characterized in that:

the composite cross-sectional shape of said homogenizer multiple optical channels is of the plus sign, and such channels are hollow.

37. A compact homogenizer module for use in an illumination system according to Claim 35,

further characterized in that:

the composite cross-sectional shape of said homogenizer multiple optical channels is of the plus sign, and such channels are solid.

38. A compact homogenizer module for use in an illumination system according to Claim 1,

further characterized in that:

the optical axes of the various channels form a bundle.

39. A compact, energy-recycling homogenizer module for use in an illumination system for optical projection,

characterized by:

a) folded optical channel means having an entry position and an exit position,

b) entry port means at said folded optical channel entry;

c) a plurality of parallel, internally-reflective longitudinal surfaces in said folded optical channel;

d) a plurality of internally-reflective latitudinal surfaces in said folded optical channel, perpendicular to said longitudinal surfaces; and

e) said longitudinal and latitudinal internally-reflective surfaces are so configured that all longitudinal sections of said optical channel have a common geometric axis; and there is an innermost longitudinal channel section, which is

surrounded by a surrounding longitudinal channel section, which is surrounded at least once more by a surrounding ring-shaped longitudinal channel section; and

f) exit port means at said folded optical channel exit position;

whereby such folded optical channel provides a complex multi-reflection uniformizing effect as most rays of a bundle of light rays in an entering beam travel with multiple complex internal reflections from entry means to exit means, and some light rays that are reflected back toward said entry port means are re-reflected in the forward direction and returned for recycling.

40. A compact, energy-recycling homogenizer module for use in an illumination system according to Claim 39,

further characterized in that:

the innermost channel is rectangular in cross-section and the outer channels are rectangular-ring-shaped.

41. A compact, energy-recycling homogenizer module for use in an illumination system according to Claim 39,

further characterized in that:

the innermost channel is rectangular in cross-section and the outer channels have a cross-section that is a composite of multiple triangles.

42. A compact, energy-recycling homogenizer module for use in an illumination system according to Claim 39,

further characterized in that:

the innermost channel is circular in cross-section and the outer channels are circular-ring-shaped.

43. A compact, energy-recycling homogenizer module for use in an illumination system according to Claim 39,

further characterized in that:

the innermost channel is rectangular in cross-section and the outer channels are circular-ring-shaped.

44. A compact, energy-recycling homogenizer module for use in an illumination system according to Claim 39,

further characterized in that:

the innermost channel is hexagonal in cross-section and the outer channels are circular-ring-shaped.

45. A compact, energy-recycling homogenizer module for use in an illumination system according to Claim 39,

further characterized in that:

the innermost channel is hexagonal in cross-section and the outer channels are rectangular-ring-shaped.

46. A compact, energy-recycling homogenizer module for use in an illumination system for beam combining

characterized by:

a) folded optical channel means having at least two entry positions and an exit position,

b) entry port means at said folded optical channel entries;

c) a plurality of parallel, internally-reflective longitudinal surfaces in said folded optical channel;

d) a plurality of internally-reflective latitudinal surfaces in said folded optical channel, perpendicular to said longitudinal surfaces; and

e) exit port means at said folded optical channel exit position;

whereby such folded optical channel provides a complex multi-reflection uniformizing effect as most rays of a bundle of light rays in an entering beam travel with multiple complex internal reflections from entry means, combine with each other, travel to exit means, and some light rays that are reflected back toward said entry port means are re-reflected in the forward direction and returned for recycling.

47. A compact, energy-recycling homogenizer module according to Claim 46, in which said optical channels are hollow.

48. A compact, energy-recycling homogenizer module according to Claim 46, in which said optical channels are solid.

49. A compact, energy-recycling homogenizer module according to Claim 46, in which said two input beams are of the same wavelength.

50. A compact, energy-recycling homogenizer module according to Claim 46, in which said two input beams are of differing wavelengths, and reflecting surfaces are optimized for the wavelengths of both input beams.

51. A compact, energy-recycling homogenizer module for use in an illumination system for beam dividing

characterized by:

a) folded optical channel means having an entry position and at least two exit positions,

b) entry port means at said folded optical channel entries;

c) a plurality of parallel, internally-reflective longitudinal surfaces in said folded optical channel;

d) a plurality of internally-reflective latitudinal surfaces in said folded optical channel, perpendicular to said longitudinal surfaces; and

e) exit port means at said folded optical channel exit positions;

whereby such folded optical channel provides a complex multi-reflection uniformizing effect as most rays of a bundle of light rays in the entering beam travel with multiple complex internal reflections from said entry port means, divide into separate beams, travel to exit means, and some light rays that are reflected back toward said entry port means are re-reflected in the forward direction and returned for recycling.

52. A compact, high-efficiency, energy-recycling according to Claim 17,

further characterized in that:

all mirrored surfaces are mirrorized by application of a reflective metal coating.

53. A compact, high-efficiency, energy-recycling illumination system according to Claim 17,

further characterized in that:

all mirrored surfaces are mirrorized by application of a reflective multilayer dielectric coating.

54. A compact, high-efficiency, energy-recycling illumination system according to Claim 14,

further characterized in that:

said mirrored surfaces are made reflective by application of a reflective metal coating.

55. A compact, high-efficiency, energy-recycling illumination system according to Claim 14,

further characterized in that:

said mirrored surfaces are made reflective by application of a reflective multilayer dielectric coating.

56. A compact energy-recycling homogenizer module for use in an illumination system according to Claim 1

further characterized in that:

internally-reflecting surfaces of input face and output face are perpendicular to the optical axes of said optical channels; and

internally-reflecting walls of the optical channels are parallel to the optical axes of the channels.

57. A method of making a compact, energy-recycling homogenizer for use in an illumination system, according to the following steps:

Step 1) Arranging a first set of internally-reflective optical channel segments starting with an entry port and reflecting from an entry-channel reflective stop for return-forwarding a complex light beam bundle into a subsequent set of internally-reflective optical channel segments;

Step 2) Arranging the subsequent set of internally-reflecting optical channel segments to forward such complex light beam bundle, now more complex, in a generally reverse direction from said entry-channel reflective stop to reflect from a subsequent-channel reflective stop, which forwards an even more complex light beam bundle; and

Step 3) Arranging a final set of internally-reflecting optical channel segments to receive such even more complex light beam bundle, now having been homogenized to maximum complexity as it transits such final optical channel in a generally forward direction from said subsequent-channel reflective stop as a homogenized light beam bundle at an exit port.

58. A method of making a compact, energy-recycling single-channel homogenizer for use in an illumination system, according to Claim 57,

further characterized in that:

there is a single-channel path leading from entry port to exit port with reflective stops for reversals at ends of entry-channel and all subsequent-channels except final channel.

59. A method of making a compact, energy-recycling plural-channel homogenizer for use in an illumination system, according to Claim 57,

further characterized by:

providing at least one additional entry port and subsequent-channel-parts, leading via reversals at reflective stops at ends of entry-channel-parts and subsequent-channel-parts to a single exit-channel with a single exit port, and

there is thus a channel path leading from each entry port to exit port with reflective stops for reversals at ends of entry-channel-parts and subsequent-channel-parts.

60. A method of making a compact, energy-recycling homogenizer for use in an illumination system, according to Claim 59,

where the total number of entry ports is two and the total number of exit ports is one.

61. A method of making a compact, energy-recycling homogenizer for use in an illumination system, according to Claim 59,

where the total number of entry ports is more than two and the total number of exit ports is one.

62. An assembled-box method of making a compact, energy-recycling homogenizer for use in an illumination system, according to Claim 57,

further characterized in the following:

providing homogenizer body having at least one segmented optical channel with a pair of parallel internally-reflective exterior wall plates, a pair of perpendicular internally-reflective ends and a set of doubly-reflective internally-reflective short plates, defining the zigzag channel in a homogenizing complex optical path from each input port to exit port, with the result that a light beam entering said input port travels a complex plural-returning reflective path to said output port.

63. An assembled-box method of making a compact, energy-recycling homogenizer according to Claim 62, further characterized in that a single entry port is provided, leading into a complex plural-returning reflective path to a single output port.

64. An assembled-box method of making a compact, energy-recycling homogenizer according to Claim 62,

further characterized in that

plural entry ports are provided, leading into a set of complex plural-returning reflective paths to a single output port.

65. An assembled-box method of making a compact, energy-recycling homogenizer according to Claim 62, further characterized in that reflective metallization is used to form internal mirrors.

66. An assembled-box method of making a compact, energy-recycling homogenizer according to Claim 62, further characterized in that multilayer dielectric coatings are used to form internal mirrors.

67. A slotted-block method of making a compact, energy-recycling homogenizer according to Claim 57, further characterized by:

providing a solid block of an optical material;

providing slots in said solid block to delineate a complex set of optical channel segments operable for homogenization of entering light.

68. A slotted-block method of making a compact, energy-recycling homogenizer according to Claim 67, further characterized in that:

there are two short slots, parallel to the axes of the optical channels and positioned at opposite ends of the block, provided with reflective means so as to define a complex , homogenizing segmented optical channel from a single entry port to a single exit port.

69. A slotted-block method of making a compact, energy-recycling homogenizer according to Claim 67, further characterized in that:

there are complementary sets of short slots, parallel to the axes of the optical channels and positioned at opposite sides of the block, provided with reflective means so as to define a set of complex, homogenizing, segmented optical channels, one from each of separate entry ports to exit port means.

70. A slotted-block method of making a compact, energy-recycling homogenizer according to Claim 69, further characterized in that:

there are complementary sets of short slots, parallel to the axes of the optical channels and positioned at opposite sides of the block, provided with reflective means so as to define a set of complex, homogenizing, segmented optical channels, one from each of separate entry ports to a shared exit port.

71. A slotted-block method of making a compact, energy-recycling homogenizer according to Claim 67, further characterized in that said slots are mirrorized after fabrication.

72. A slotted-block method of making a compact, energy-recycling homogenizer according to Claim 71, further characterized in that said slots are made capable of total internal reflection after fabrication, by at least one of chemical polishing, mechanical polishing, and chemical/mechanical polishing.

73. A slotted-block method of making a compact, energy-recycling homogenizer according to Claim 71, further characterized in that said slots are mirrorized, after fabrication, by forming a reflective metallic coating on the inside surfaces of each slot.

74. The method of making a homogenizing beam combiner

characterized by

fabricating a body having a multiplicity of internally-reflective optical channel arms in zigzag relationship, including at least two entry channel arms, an exit channel arm, and at least one intermediate channel arm;

making entry apertures forming entry ports in respectively related internally-reflective entry channel arms;

fabricating reflective channel stop means which reflect entering beams via separate channel arms to a conjoined final channel arm which is the exit channel arm;

fabricating an exit port at terminus of said conjoined final beam path segment;

whereby the light path has plural entry channel segments and a conjoined final beam path segment with a combined-beam terminus.

75. The method of making a homogenizing beam combiner, according to Claim 74

further characterized by

fabricating said optical channel arms of a solid optical material; and

fabricating anti-reflection coatings at said entry ports and at said exit port.

76. The method of making a homogenizing beam divider

characterized by

fabricating a body having at a multiplicity of internally-reflective optical channel arms in zigzag relationship, including at least two exit channel arms, an entry channel arm, and at least one intermediate channel arm;

making exit apertures forming exit ports in respectively related internally-reflective exit channel arms;

fabricating reflective channel stop means which reflect an entering beam via the entry channel arm to a set of final channel arms which are the exit channel arms;

fabricating exit ports at each terminus of said final beam path segments at said exit ports;

whereby the light path has a single entry channel segment, and a set of final beam path segments at said exit ports.

77. The method of making a homogenizing beam divider, according to Claim 76.

further characterized by:

fabricating said optical channel arms of a solid optical material; and

fabricating anti-reflection coatings at said entry port and at said exit ports.

78. The method of making a homogenizing beam transfer device having a different number of internally-reflective channel means for beam entry and for beam exit

characterized by

fabricating a body having a multiplicity of internally-reflective optical channel arms in zigzag relationship, including a set of at least one entry channel arm and a set of at least one exit channel arm, with an optional set of intermediate channel arms connecting said set of entry channel arms to said set of exit channel arms;

making apertures forming entry ports in respectively related internally-reflective entry channel arms;

fabricating reflective channel stop means which reflect light beams entering via said set of entry channel arms, such beams each generally reflecting into a subsequent channel arm, but being subject to undesirable reverse reflection of central rays back through the entry port; and

fabricating reflective-channel-stop central ray redirection means, associated with said reflective channel stop means, arranged to reflect central rays according to designated angles to limit re-reflection into the entry aperture.